

Brain Image Registration Based on Cortical Contour Mapping

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Abstract

In this paper we address the problem of brain image registration, and we present a new, nonlinear registration technique. In the first step of our technique we obtain a point-to-point mapping between the outer cortical contours of the brain images using an elastic string algorithm. In the second step we register the two images based on the point-to-point correspondence established in the first step. We propose a new, nonlinear registration transformation, which is based on a spatially variable scaling and rotation that can describe highly nonlinear deformations. Finally, we test our algorithm on two different registration problems.

1 Introduction

The problem of image registration has been extensively studied in the literature. Most of the existing methods are based on transformations that are either linear or yield a maximum region overlap. The former apply to cases where the images to be registered are images of exactly the same object and differ only by a rotation, a translation, and a scaling. The latter can describe nonlinear deformations, but depend strongly on a careful initial rough registration and on the matching of the intensity values of the two images. This is a limiting factor if the images are acquired through different modalities.

In this paper we address the problem of brain image registration, with emphasis on nonlinear deformations, i.e. deformations that cannot be described by linear transformations. We present a new registration technique that is based on the geometry of the imaged objects rather than the intensity values of the images. This overcomes some of the limitations of the maximum region overlap based techniques.

2 Registration Technique

We decompose the registration of brain images into two steps. In the first step we obtain a point-to-point mapping between the outer cortical contours of the brain images. This mapping is based on an active contour algorithm. The physical equivalent of an active contour is an elastic string that deforms under the presence of internal and external forces. The internal forces maintain the connectivity of the string and are responsible for its elastic behavior. The external forces provide a mechanism that matches the string to the object contours to be extracted (in our problem the outer cortical contours). The details of this algorithm can be found in [1, 2, 3, 4]. The one-to-one mapping obtained through the active contour algorithm provides a large number of landmark points, which are in correspondence between the two images to be registered.

In the second step we register the two images using the point-to-point correspondence established in the first step. We propose a new, nonlinear registration transformation, which is based on a spatially variable scaling and rotation. Specifically, we first define two polar coordinate systems, one in each image. The origins of these two coordinate systems are placed at a central point of the brain, and are assumed to form a matching pair. We denote by (r_i, ϕ_i) , $i = 1, \dots, N$, the radial and angular coordinates, respectively, of the N points of the cortical boundary in the first image, denoted by I_1 . We also denote by (R_i, Φ_i) , $i = 1, \dots, N$, the polar coordinates of their corresponding points on the cortical boundary in the second image, I_2 . We then define a scaling $s(\phi)$ and a rotation $\theta(\phi)$, that maps each point of the cortical boundary in I_1 to a point in I_2 . The functions $s(\cdot)$ and $\theta(\cdot)$ are only known for $\phi = \phi_1, \dots, \phi_N$:

$$s(\phi_i) = \frac{R_i}{r_i} \quad (1)$$

$$\theta(\phi_i) = \Phi_i - \phi_i. \quad (2)$$

To obtain a value for $s(\cdot)$ and $\theta(\cdot)$ for every ϕ we apply a linear interpolation.

After having defined the functions $s(\cdot)$ and $\theta(\cdot)$ for the cortical boundary points, we scale and rotate each radial line originating from the origin of the polar coordinate system in I_1 according to the corresponding scaling and rotation of the cortical contour point that belongs to this line. Specifically if (r, ϕ) is a point in I_1 , its corresponding point in I_2 has polar coordinates (R, Φ) given by

$$R = rs(\phi) \quad (3)$$

$$\Phi = \phi + \theta(\phi). \quad (4)$$

By applying this transformation to all of the radial lines — which span the whole image — we warp the full 2-D image, bringing into correspondence the two cortical contours. It is worth noting that the scaling and rotation applied varies from one radial line to another, and, therefore, our transformation can describe highly nonlinear deformations, a very useful feature for inter-subject registration. A detailed description of our approach is given in [5].

3 Experimental Results

We have tested our algorithm on two different problems. We first consider the registration of a post-mortem photograph of a baboon brain cross-section and an MR image of approximately the same cross-section (Fig. 1). Applying our registration algorithm to this pair of images yields the image of Fig. 2a whose outline is shown in Fig. 2b superimposed onto the MR image. Figure 2b reveals that an accurate registration was obtained; the wavy shape of the cortex in Fig. 1a was eliminated, and the highly nonlinear deformation around the temporal lobe area was compensated.

We have also tested our algorithm on the two images of Fig. 3. In Fig. 3a we show a digitized Talairach atlas image and in Fig. 3b an MR image taken at approximately the same transaxial plane. Application of our method yields the transformed image of Fig. 4a whose outline is shown in Fig. 4b superimposed on the MR image. A fairly good registration accuracy is revealed in Fig. 4b.

4 Summary

We presented a new, two-step approach for brain image registration. In the first step we obtained a

one-to-one mapping between the cortical outlines. In the second step, we deform one of these outlines to match the second one. The deformation of the cortical outlines then induces a deformation to the rest of the image, through a spatially variable radial scaling and rotation.

The main advantages of our approach are twofold. First, it can describe nonlinear deformations and second, it minimizes human interaction since a large number of landmark points are automatically determined through the active contour algorithm. The major limitation of our approach is that it is based on the assumption that points that are in geometric correspondence with each other through the isometric mapping defined by our active contour algorithm, are also in anatomical correspondence. However, our experimental results show that even under this assumption, a good registration is obtained. The relief of this assumption through a generalization of the point-to-point mapping between the cortical contours is of primary interest in our future research.

References

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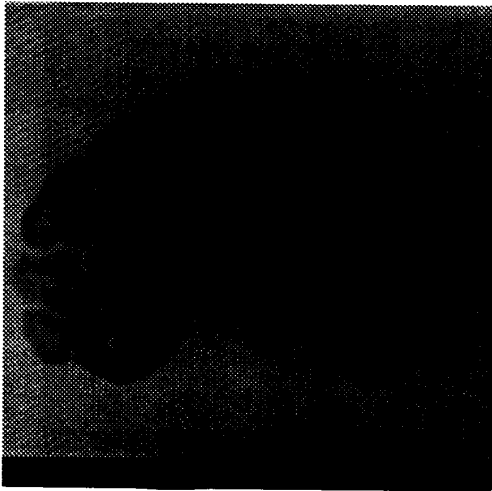


Figure 1a. A post-mortem photograph of a baboon brain cross-section.

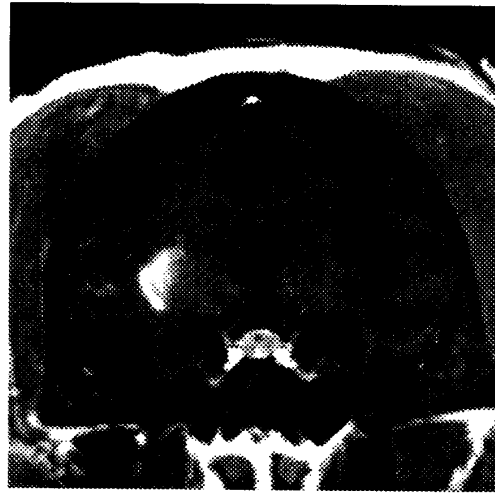


Figure 1b. An MR image of approximately the same cross-section of the baboon brain

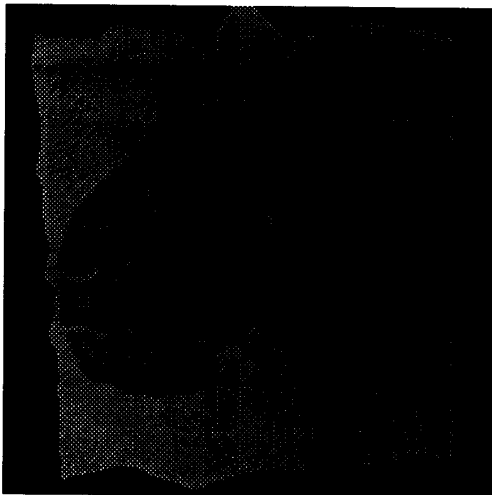


Figure 2a. The transformed image of Fig. 1a using our radially linear transformation.

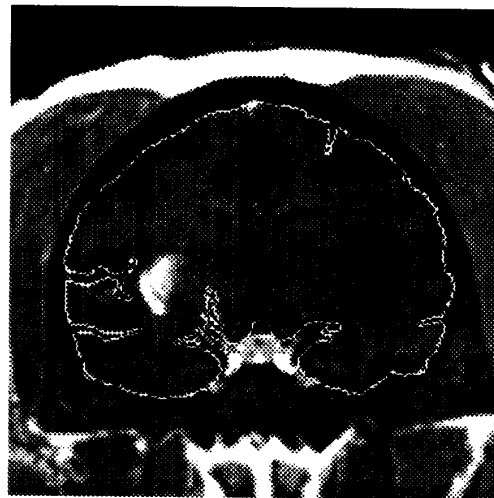


Figure 2b. The cortical outline of (a) superimposed on Fig. 1b.

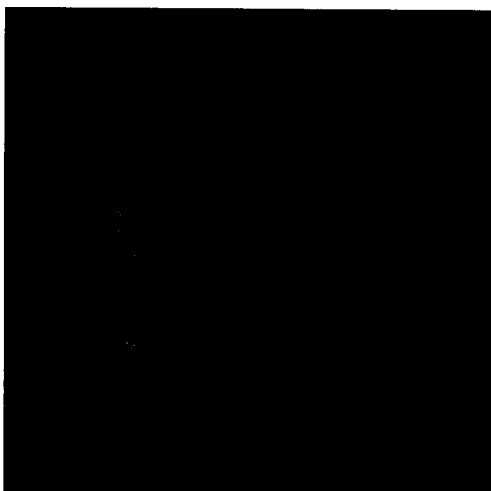


Figure 3a. A Talairach atlas image of the human brain.

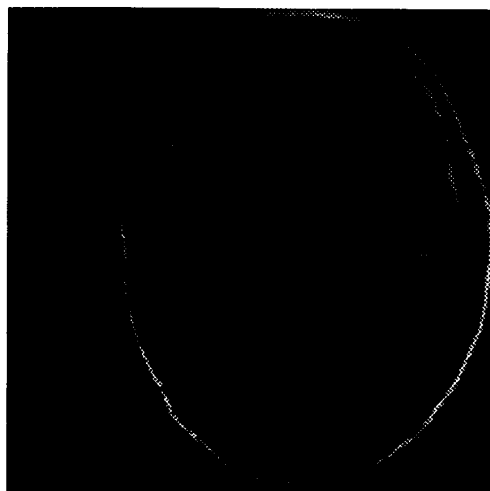


Figure 3b. An MR transaxial image of the same, approximately, cross-section.

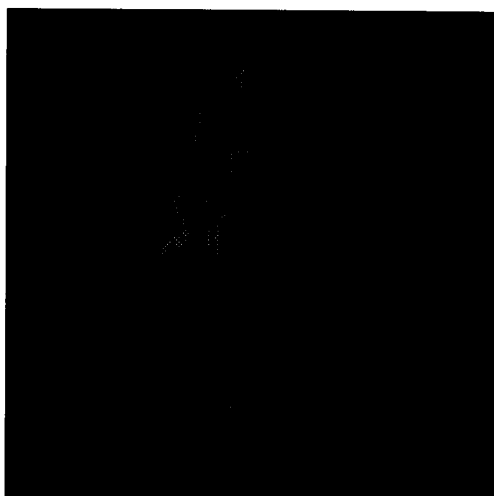


Figure 4a. The transformed atlas image using the radially linear transformation.

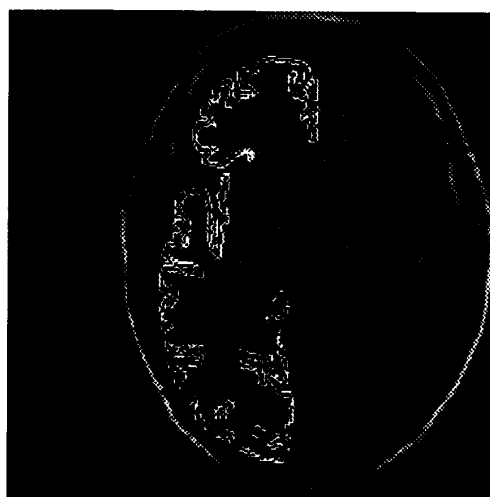


Figure 4b. The cortical outline of (a) superimposed on the MR image.